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Gas-Liquid Mass Transfer in Bubble Column and Oscillatory Baffled Column Using Electrical Resistance Tomography (ERT)

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Abstract: Mixing operations are encountered widely throughout productive industry in processes involving physical and chemical change, but due to its complexity theoretical approaches are very limited. This paper described the use of Electrical Resistance Tomography (ERT) in characterizing and quantifying gas-liquid mixing in bubble column and oscillatory baffled column. The Electrical Resistance Tomography (ERT) technique offers a unique opportunity for a non-invasive internal visualization of gas-liquid mixing. The parameters investigated are conductivity tomogram, gas hold up and power number.The experimental work was carried out in bubble column (BC) with a diameter of 15 cm and a height of 100 cm and oscillatory baffled column (OBC) with 14.5 cm diameter and 72 cm height. In addition, the column is equipped with ITS P2000 ERT unit where it is fitted with four planes of sixteen stainless steel ERT electrodes. The results shows OBC give a higher mass transfer rate rather than BC.

Keywords: Electrical Resistance Tomography, Gas hold up, Gas-liquid Mixing, Volumetric Mass Transfer Coefficient

1.0 INTRODUCTION

Gas/liquid multiphase flows occur in a wide range of chemical and biochemical processing. Agitated vessel, bubble columns (BC), and airlift columns are the most commonly used devices for enhancing gas–liquid mass transfer [1].Oscillatory baffled column is a new generation of bubble column which can be operated in batch or continuous mode. OBC incorporate equally spaced orifice baffles together with fluid oscillation, providing significantly different fluid dynamicsthan BC[2].The gas–liquid volumetric mass transfer coefficient in an OBC could be six times higher than that in a BC and 75% higher than that in a stirred tank fermenter involving a yeast culture[3].

The best technique in determining flow behavior in a vessel is the visualization of the internal flow in real situation. Among possible technique for visualization of the dynamics multiphase system is Electrical Resistance Tomography (ERT)[4]. Among the advantages ofERT include non-intrusive measurement, high temporal resolution and non-radiological characteristics[5].Electrical Resistance Tomography (ERT) is a measurement technique for obtaining information aboutthe contents of process vessels and pipelines. Multiple electrodes are arranged around the boundary ofthe vessel at fixed locations in such a way that they make electrical contact with the fluid inside thevessel but do not affect the flow or movement of materials.

This paper aimed to predict gas hold up and mass transfer for gas-liquid mixing in bubble column and oscillatory baffled column by using correlation based on electrical resistant tomography data. The parameters will be take into accounts are conductivity tomograms, gas hold up, power number and mass transfer coefficient, *kLa*. Comparison will be done at the optimum conditions for particular vessel based on a few operating conditions of experiments were runs.

2.0 MATERIALS AND METHODS

ERT system

The ITS P2000 ERT system was used in these studies. It is consisting of three components namely; the sensor electrodes/process vessel, the data acquisition system (DAS) and image reconstruction algorithm (see Fig. 1).

Fig. 1 Experimental apparatus: (a) data acquisition system (b) image reconstruction(c) Bubble column (d) Oscillatory Baffled Column

Sixteen stainless steel electrodeswith 4 planes are mounted on the inner wall of equipments with equal space, which are used to inject a current between a pair of electrodes and measure the resultant voltage difference between remaining electrode pairs according to a predefined measurement protocol. Sensing array was connected to DAS with co-axial cable for collecting the real-time instantaneous signals from spatial sensing array that reflect the two-dimension (2-D) or three dimension (3-D) distribution of measured field [6]. The data must be collected quickly and accurately in order to track small changes of conductivity in real-time thus allowing the image reconstruction algorithm to provide an accurate measurement of the true conductivity distribution. The P2000 system collect 104s voltage values per data frame. Its data acquisition speed is 20 frames s^{-1} at frequency of 9.6 kHz. With this speed, P2000 is good enough for tracking conductivity changes.

Experimental systems and operating conditions

The experiment runs were for gas dispersion and without gas. Without gas test is used to be a reference data. The perforated plate was fitted at the bottom of oscillatory baffled column. In all the experiments, tap water (density, 998.2 kgm^{-3}; viscosity, 0.001003 $kgm^{-1}s^{-1}$) was used as the liquid phase and air at room temperature (27^0C), which was measured by flow-meter, was introduced into the bottom of all equipments as gas phase. The parameters were used in these studies were shown in Table 1.

Table 1 Operating Conditions

Equipment/Parameter	**Agitation Speed (RPM)**	**Gas Flow rate (L/min)**	**No. of Sparger**	**Amplitude (cm)**	**Frequency (Hz)**
Bubble column	-	2,4,6,8	5	-	-
Oscillatory Baffled Column	-	2,4,6,8	-	5,6,7	1,2

3.0 RESULTS AND DISCUSSIONS

This section will present main results based on optimal condition for all equipments used. A total number of 200 frames were recorded for every each experiments conducted for analyzing purpose. Based on analysis data, bubble column with 5 spargersand gas flowrate at 6 L/min gave the best results while oscillation amplitude at 7 cm with 1 Hz oscillation frequency and gas flowrate 6 L/min generate optimum results.

Conductivity Tomogram

Reconstructed images of the data obtained from the four rings of electrodes indicate regions of high (red color) and low (blue color) conductivity shown in Fig. 2. The top row image corresponds to the reference data which is absence of gasfollowing with conductivity tomogram for bubble column at 6 L/min gas flowrate and 5spargers is turning on andthe last row is conductivity tomogram for oscillatory baffled column at 7 mm of oscillatory amplitude coupling with 1 Hz of oscillation frequency and 6 L/min gas flowrate.

Mixing process is not going well based on conductivity tomogram produced by ERT at bubble column equipment. At the plane 3, gas phase is not mix well with water showing by blue color (gas) concentrated at the area closed to the wall. Yellow to greenish color are dominant on conductivity tomogram for bubble column. For OBC, gas-liquid mix well at plane 2 and 3 can be clearly seen on conductivity tomogram which yellow to red color are dominant. This condition is happened because of baffled are present at plane 2 and 3. Baffled is specially designed for increase the mixing process in oscillatory baffled column.

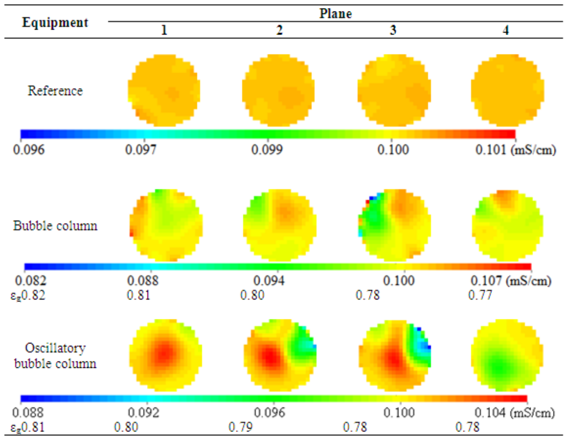

Fig. 2 Conductivity tomogram

Gas Holdup

Gas holdup is a dimensionless parameter was used for design purposes that characterize transport phenomena of gas-liquid systems. This parameter is important in the design and analysis of gas-liquid contactors such as bubble columns and agitated vessel.Usually gas Hold-up can be calculated by using the Maxwell relationship (the conductivity data obtained from ERT):

$$\varepsilon_{g,i} = \frac{2\sigma_1 + \sigma_2 - 2\sigma_{mc} - \sigma_{mc}\sigma_2 / \sigma_1}{\sigma_{mc} - \sigma_2 / \sigma_1 + 2(\sigma_1 - \sigma_2)} \quad (1)$$

Which is σ_1 is the conductivity of the first phase, σ_2 the conductivity of the second phase, and σ_{mc} is the (measured) mixture conductivity. If the second phase is non-conductive material, such as air in this study, the above equation can be simplified as:

$$\varepsilon_{g,i} = \frac{2\sigma_1 - 2\sigma_{mc}}{2\sigma_1 + \sigma_{mc}} \quad (2)$$

The equation (2) in the conductivity measurement (mS/cm) leads to the mapping of the gas hold up for all experiments. Results shown that gas hold up in bubble column ranging from 77 to 82% and oscillatory bubble column is 78 – 81% respectively. Gas hold up values for bubble columns is not consistent for 4 planes with high averaged range values obtained. For the OBC, the gas hold up values is not having a big range for all planes shown that gas-liquid mix well.

Power Density

The power density, P/V, can be related to the dispersion into the gas liquid mixing according to the following equation 3 for bubble column [8]and equation 4 for oscillatory baffled column[8]. Higher power density values showing that the mixing process is better.

$$\left(\frac{P}{V}\right)_{BC} = \sqrt[c]{\frac{\varepsilon_g}{a_2}} \quad (3)$$

$$\left(\frac{P}{V}\right)_{OBC} = \sqrt[c]{\frac{\varepsilon_g}{a_2}} \quad (4)$$

Where a_2= 0.0003 and c = 0.89 for bubble column and a_2= 0.0002 and c = 0.87 for OBC [9].

Table 2 Power Number

Equipment	**Power Number, (P/V) (W/m^3)**
Bubble column	7010.185
Oscillatory bubble column	13654.689

Table 3 shown power number for average gas hold up obtained. From the calculation, OBC give high values for power number compare to bubble column. Higher power number let to better mixing intensity result a higher gas hold up obtained.

Mass Transfer Coefficient, kLa

The volumetric mass transfer coefficient, kLa was obtained using equation 5 [10]for BC and equation 7 for OBC[9].

$$k_L a = a_4 U_g^f \quad (5)$$

Where a4 = 0.079 and f = 0.81.

$$U_G = \frac{\dot{V}}{A} \quad (6)$$

UGis superficial gas velocity (m/sec), $\dot{V}$ is volumetric flow rate of gas (m3/s) and Ais cross sectional area (m2)

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$$k_L a = 0.012(P/V)_{OBC}^{0.26} U_g^{0.4} \quad (7)$$

Results shown OBC give higher kLa values which is 0.106 (1/s) compare to BC with 3.89x10-4 (1/s). The values is in prediction which is OBC is better than BC in line with the study by [9].For bubble column gas bubble are enough to travel along column with five spargers are opened. The breaking of bubble just depends onto collisions of bubble itself so the mass transfers are quite low to give the low kLa value. Baffled at column are specially designed to OBC as a special tools to break the gas bubble to smaller size addition to oscillation of liquid by piston. This condition can enhance mass transfer rate consequently better mixing process was achieved.

4.0 CONCLUSIONS

Based on the observations made in this work, ERT technique is capable to visualize gas-liquid mixing in bubble column and oscillatory baffled column. The technique successfully captures the gas dispersion in particular vessel. Oscillatory baffled column shows to be the best equipment in gas-liquid mixing process compare to others vessel based on higher gas hold up values and *kLa*value. The results are supported with previous research by [3,9].

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